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ABSTRACT

The naive conceptions that children develop tacitly or explicitly, outside the classroom, contribute to their interpretation of the teacher's words, paragraphs in a book, or the results of an experiment. These conceptions (or "alternative frameworks") may persist even in the face of systematic teaching of competing scientific concepts and models. In addition, they can be very resistent to change. The study, an attempt to explore concept formation and attainment by children (N=22) over a period of time, focuses on alternative frameworks and an approach used to examine them. The interview-about-instances (IAI) approach consists of a dyadic interview where the focus of attention is a deck of stimulus cards depicting physics situations which students are required to classify as examples or non-examples of a concept. The approach attempts to describe the conceptual framework students are using rather than present a critical expose of the inadequacies of their thinking. Results of interviews related to the concepts of force and energy indicate that students tended to reply in a general non-specialist way, recognizing situations as "physics" questions, but fluctuating between intuition and algorithm as they answered. It is suggested that effective teaching involves building on the students' pre-determined knowledge. (JN)

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An Exploration of Students' Understanding of the Concepts 'Force' and 'Energy'

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An exploration of students' understanding of the concepts 'force' and 'energy'.

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"You have got the impression that contemporary physics is based on concepts somewhat analogous to the smile of the absent cat".

Albert Einstein,
quoted in Viscount Samuel (ch.19), J. Bowle.

Introduction

Scientists, particularly physicists, have to become accustomed to working with conflicting models or theories. They have to live with indeterminacies. The wave-particle duality in the nature of light; the whereabouts and momentum of electrons in quantum theory, serve as examples. The mark of the physicist is his use of appropriate models to build imaginative pictures of the processes he is observing. He might use a wave model to describe the bulk movement of water, but a particulate model to describe its surface tension. The disconcerted layman might press to have explained to him the reasons for such vagary. What he requires is not the equations, the symbols, or scientific arguments that satisfy the physicist. What he does need is an explanation of the conceptual framework within which the statements are made. He needs to know what sense it makes, to say such things. The language that is used to communicate the ideas has to be meaningful to both parties.

The concepts, and conceptual frameworks, that make up these models form part of 'accepted physics'. Communicating the sense of the models poses a number of problems. Physics teachers may have lived with their chosen subject so long that its technical terms and its ways of speaking, are all so well known and fluently used that they seem to be second nature. It is hard to remember when 'kinetic energy', 'vector', 'potential', 'interferenc held powerful connotations for others, whilst making only a flimsy kind of sense for ourselves. However much one might wish to, there is no easy way of 'putting out of mind', even temporarily, the cumulative experience of concepts and language, to put oneself in the position of the youngster who meets the language for the first time.

The present study is an attempt to explore concepts - their formation, and attainment, by youngsters over a period of time. Having talked to children in schools it is clear that they construct a coherent idea of the world based on their experiences. These ideas are individual, idiosyncratic hypotheses and speculations about events and conversations. Words, meanings and experiences are construed and developed into personal interpretations of science. Naturally, there might be little contact, and maybe no understanding, between teacher and pupil when both approach the subject with widely differing conceptual frameworks. I would maintain that

exploring a person's 'alternative framework' is an important part of being able to teach them physics effectively.

After this brief introduction I will develop the notion of 'alternative frameworks'; discuss how they might be explored; give some examples from interviews about the concepts of 'force' and 'energy'; and finally summarise some of the ideas.

Alternative Frameworks

The naive conceptions that children develop, tacitly or explicitly, outside the classroom, contribute to their interpretation of the teacher's words, paragraphs in a book, or the results of an experiment. The term 'alternative framework' has come from the work of Driver (1973). Her study with Easley (1978) suggested that such frameworks may persist even in the face of systematic teaching of competing scientific concepts and models. They can be very resistant to change (see Dahlgren 1978), and to change them means we must be aware of them.

Only then is it likely that we can present a more scientific perspective, and provide learning experiences that will allow them to modify and develop their interpretations towards it. It is an argument that would want to supplant the word 'misconception'. A different teaching strategy can be adopted if we accept that a pupil doesn't just 'not understand' but 'understands differently'. An alternative framework may well be sophisticated and rational, logical and consistent, despite its variance with 'agreed physics.'

The Interview-About-Instances Approach

The Interview-About-Instances (I.A.I.) approach has been developed from the work of Osborne and Gilbert (1979). It consists of a dyadic interview where the focus of attention is a deck of stimulus cards. These depict situations in physics which the pupil is required to classify as examples or non-examples of a concept. So far work has been carried out on the concepts, 'work', 'electric current', 'light', 'force' and 'energy'. Each act of classification is open for discussion; the interviewer probes the reasons for the choice. An informal dialogue is allowed to develop around the cards; the conversation is audio-recorded and later transcribed. The data, then, is both structured (focused on a pre-arranged, ordered set of cards) and open ended (the pupils are encouraged to respond freely to each card).

The situations on each card show stick-people line drawings, and carry a question, or two. Between ten and twenty different instances are presented at each interview, the end point depends on the pupils, their ages, the length and detail of their responses. Towards the middle of the session they are asked for their summary, or definition of the concept. This kind of method means that I can study:-

(a) their understanding of some of the basic attributes of the concept

(b) how the common, societal meaning of a word impinges on the pupils' more precise, physics, meaning

(c) the rules of classification they are employing

(d) how the concept is associated with other concepts - how it is arranged in their framework of ideas.

The interview tape is transcribed and annotated as faithfully as is possible. It is then divided into several categories depending on the context of the conversation. This helps to highlight the hypothesis, or model, by which a youngster is working.

The interview approach I have just described is an attempt at gaining some insight into children's scientific ideas. Rather than presenting a critical expose of the inadequacies of their thinking, it tries to describe the conceptual framework a pupil is using. Here, I will discuss the results of the interviews, giving examples and quotations from individual transcripts. In a later section I will look for some common features in what they say.

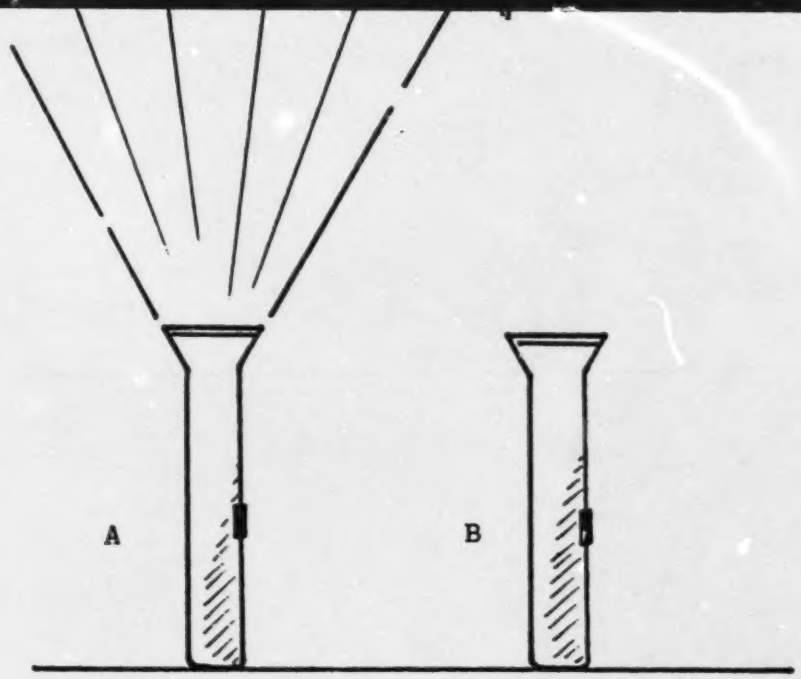
Some Results from the Interviews on 'Force' and 'Energy'

The 'force' cards, developed and piloted first, were used in a final version with twenty-two pupils between the ages of eleven and eighteen years. All the students over the age of fifteen were involved in 'O' and 'A' level courses. The others ranged from no formal science (in primary school), through junior combined science courses, to fourth year C.S.E. level.

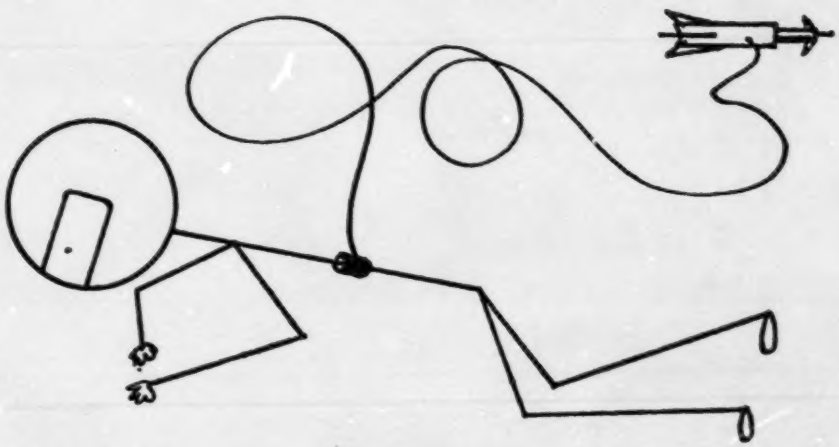
I have presented the extracts here as a series of arguments. The pupils would most commonly begin each card by labelling what forces they could identify in the picture.

"yes ... there's a force in his legs..."

"no... there's no force ... he's just floating"



Two similar torches. Has one more force acting on it than the other?

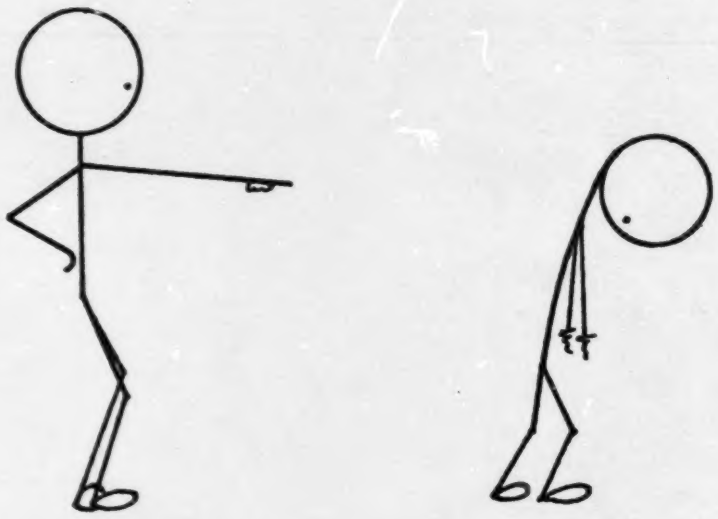


An astronaut floating in space. Are there any forces here?

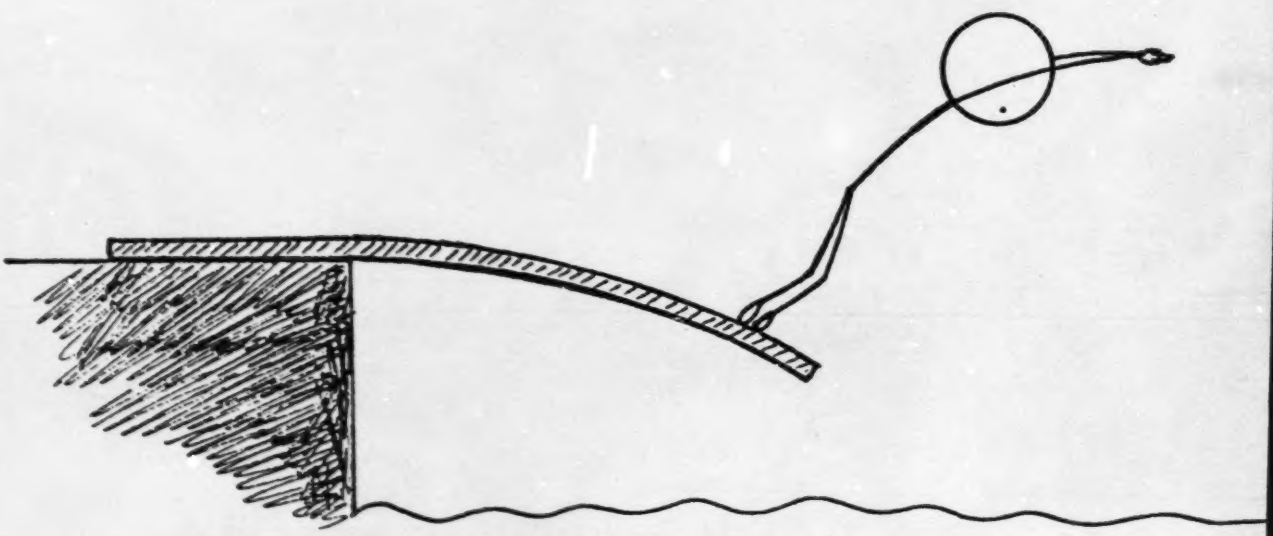
Two examples of the cards used in the 'force' interviews.

Two examples of the cards used in the 'force' interviews.

Being told what to do. Is force being used here?



Diving into a pool. Are there any forces here?



At some point I would probe some of the responses, perhaps ask for directions or relative magnitudes,or query the origin or point of application of the force. The arguments I have used seem the most recurrent.

(a) Static forces and forces-of-movement :

In the majority of interviews, forces were associated with movement- in fact,were often identified solely by the presence of movement. Sometimes this was made explicit, often it was implied in what was said. In some cases 'movement' is akin to the physicist's notion of momentum.

> "well force is movement ... isn't it, not all the time, but in physics I think of movement" (16 year old)

> "No .... well I've always thought of forces in movement, you see, and there's no movement in that picture, is there, you see" (14 year old)

[the card shows a book lying on a table]

> "forces are moving things ... you see they're not moving" (15 year old)

> "the air is moving ... so there's got to be a force" (11 year old)

> "sledging down a hill in the snow ..... yes there are forces ... moving forces" (14 year old)

> "now let me think .. 6 .. force is a moving object, or moving things ... and energy is ... you have to work up energy and store it" (16 year old)

She was commenting on the difference between 'force' and 'energy'.

> "the book ... well it's being held ... it's a kind of force ... but there doesn't seem to be anything because it's not moving ... it's just lying there." (16 year old)

Few pupils recognised forces existing in stationary objects, except where they were obviously glued or fixed together permanently.

> "I suppose things are held together by forces as well" (16 year old)

> "forces hold them together" [the book and table]

Not even the 18 year olds discussed forces in terms of mass or acceleration. There was no mention of resultant forces or momentum, and few used the language of physics to describe the situations they were discussing. Even though they seemed to accept that there was a specialised meaning for the word in physics lessons, they would not necessarily use the accompanying terminology to talk about it.

(b) Contact and non-contact forces

The overall view was that two objects needed to be in contact before a force could be applied. Contact was used as the prime criterion in deciding between the 'physics' force and the societal meaning for the word; a compulsion to do something. This was sometimes seen as a mental force as in "a force of habit", or "teacher can force you to do something" or "I have to force myself to think", as one young lady said. A physics force is different:-

> "force is when you are dragging things along" (14 year old)

> "Contact .. no ... not everything ... no ... though it does, you do have to have something in contact". (17 year old)

Here he was clearly struggling with a number of conflicting thoughts and couldn't shake the conviction that forces needed contact.

> "You must have a ... a medium ... to travel through .. for forces to travel through" (17 year old)

> "well a force is always applied to something, he's pushing the golf club and the golf club's pushing the ball".

> "gravitational force - and nobody knows how it works - does, in fact [not need contact] ... nothing really touches anybody yet we're held down by some kind of force that acts upon us". (16 year old)

Force was sometimes seen in the way that a physicist would describe impulse (force x time), as the change of momentum and not the rate of change of momentum.

> "the ball .... by hitting the ground is able to move off again .. by .. well it's eh .. I suppose the force it lands with you know" (14 year old)

"diving into the pool ... there is a force as you hit the water"
(11 year old)

(c) 'Internal'and 'External' agents

All of the pupils, particularly the younger ones, showed a tendency to anthropomorphism and animism, supporting the work of Osborne (1980).

"The diving board ... just swings back up" (12 year old)

" ... well it's [a golf ball] just pushing away from the gravity because it wants to move up" (15 year old)

"It [the diving board] forces up the diver ... well it's forcing itself to stay up ... it's also being pulled by gravity but, it's sort of working against the two". (17 year old)

Energy was seen as both a result of forces acting upon objects, and as a producer of forces in the first place. The distinction between 'force' and 'energy' is often blurred, the words frequently being used interchangeably. Both were sometimes called the 'power' required to do something. These views lead to the notion that, if forces derive from energy, and a source of energy can be used up, then forces too, are consumable. A 16 year old,'O' level candidate described the reduction in the force of a moving ball as

"the strength of the movement is getting weaker"

" .. 7 .. well I suppose the force, you know, it's an energy, so ... as the ball is moving it's losing energy, like when a person runs .. they get tired" (15 year old)

"there's the force of gravity pushing it down and the force of all the energy and power in it [a space rocket] trying to push it up"
(13 year old)

"the golfball gets its force from the golfer's arm ... which is energy .. so he's changing energy into force" (14 year old)

"and the forces of energy make it go ,to travel" (14 year old)

"for a force to be applied it needs energy" (17 year old)

"but if energy is given out .. then there must be a force .. 4 .. I suppose .. 7 .. so . the energy is used to apply a . to apply a force to the filament [of a torch bulb] . . 'cos when energy's used there must be .. it must be applying a force to something". (18 year old)

It is the network of concepts related in this way that forms a 'framework'. In order to discuss a particular concept a student must introduce other terms, so exposing his connecting ideas. The greatest variation of ideas came in discussing the role that gravity plays in our affairs. The most common view was that gravity could not operate in a vacuum, hence no air no force. Weight and gravity were frequently unrelated; they were separate entities. Gravity frequently had a sharp upper limit, usually where the atmosphere ended too, except for a fifteen year old who speculated on two gravities. One came up from the centre of the earth, pushing objects so that they didn't go down through the earth's crust, holding tables, chairs and people up. The other came down from above and pushed flying objects back down to earth. We live in the sandwich area that exists between the two gravities.

Gravity was sometimes seen as getting stronger as the distance from the earth increased. Nothing short of the 'power' a spacecraft had, could break through the barrier. On the moon an astronaut would need something heavy (a large rock, big boots) to prevent him floating off.

The Energy Interviews

Separate cards on the concept of energy are now only out of the piloting stage, some twelve interviews in all.

They have produced similar results when discussed along side 'force' concepts. A common sequence was that

"energy produces power, power produces force and force produces movement" (16 year old)

It seems that energy can be stored or be kinetic energy, and as it is consumed i movement so the force it can produce will diminish. Muscles change energy into force. Thus a separation was made between it being inside an object; or applied by an external agent to an object. The internal aspect was treated much as if energy is an ingredient, to be found along

side vitamins in morning breakfast cereal. Or as a chemical ingredient in oil, coal or other fuels. A ball rolling along a horizontal table didn't have energy, it had been given energy, so that energy was seen to be applied by somethings, and applied to others.

In this section I have given a series of examples of the way children talk about the concepts of 'force' and 'energy'. Even the 16 - 18 year olds, who tended to identify with the attitudes of the physicist, replied in a general, non-specialist way. They recognised the situations as 'physics' questions, but then fluctuated between intuition and algorithm as they answered.

A Summary of Ideas

In this last section, I will not make generalisations about all children's understanding of concepts from such a small sample, covering such a wide age range. I would, however, hope to draw attention to some features that may be of general interest.

(a) The interviewees adopted particular strategies in the interview. They were required to leave their science lesson to talk to a 'man-from-the-university' about 'forces' or 'energy'. Generally, with the exception of the 'A' level students, they came without ready-made answers. They tended to derive a model, or hypothesis, after some 6 or 8 cards and would develop this further as the interview progressed. They often seemed unconcerned that aspects of their own model should be contradictory. To develop an idea that coped with the cards, despite a few loose-ends, seemed very pleasing.

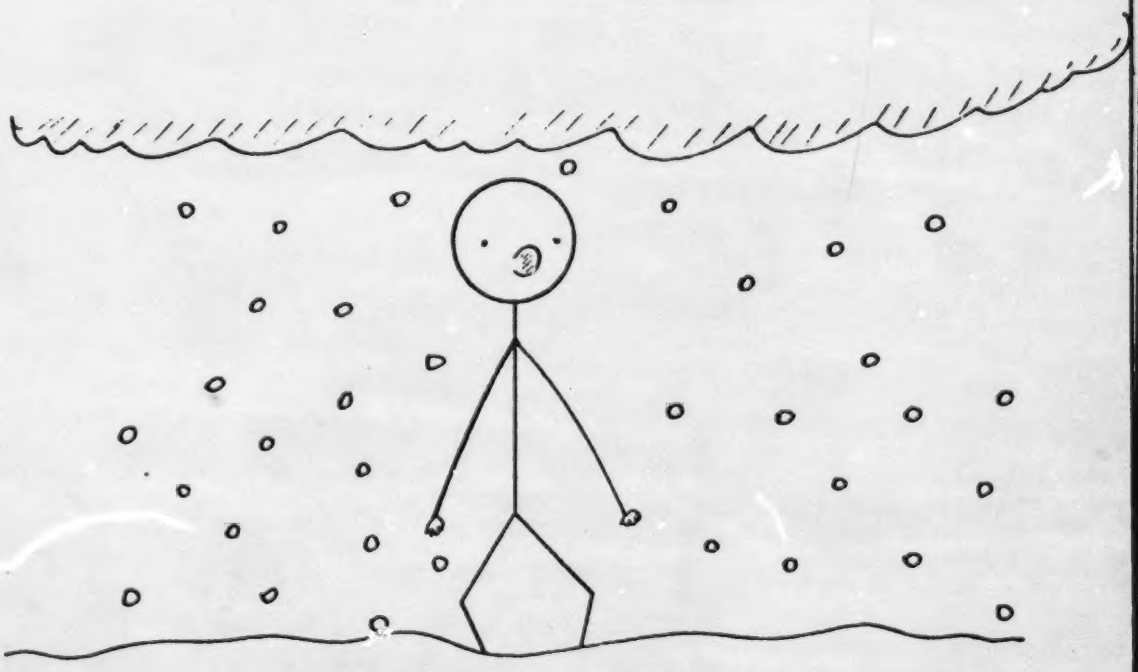
(b) The important part of developing a hypothesis was to make up rules that would 'satisfy' the cards. To some their hypotheses had to have some consistency.

> "force on the moon ... no .. it hasn't got any gravity, and gravity's got force .. and so there's no force on the moon"
>
> (15 year old)

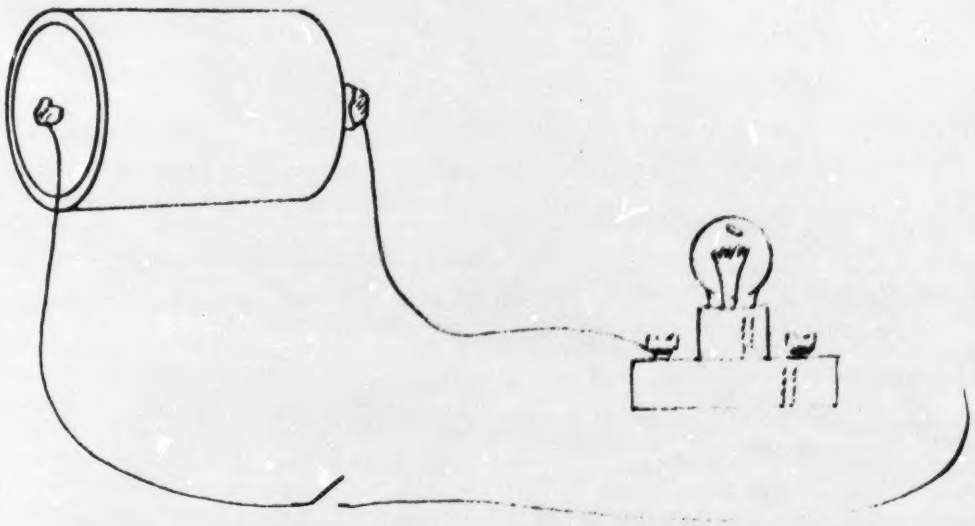
The rules could sometimes be over-generalisations from one incident, or event, in science. They were sometimes simplified forms of scientific laws, ("action equals reaction"). In some cases they were idiosyncratic rules generated spontaneously as the interview progressed.

Examples of the cards from the energy interviews.

A chemical reaction.
Is there any energy here?



A person in the snow. Is there any energy here?



A battery, bulb and switch. Is there any energy here?

205 I mmm

206 J and gravitys got force

207 I uhum

208 J and so theres no force on the moon

209 I uhum . . and so what would happen to the astronaut I mean would he just sort of stay like [that

210 J [oh no hell jump up in the air and float in the air

211 I and what and carry on . . for ever

212 J no::o yea he probably unless hes got a heavy weight on him which he hasnt

213 I why would that make a difference

214 J because . the heaviness would just . . you have to be really heavy on the moon dont you otherwise youll float off . . see . theres no gravity

215 I okay . so . so if youre really heavy that that gets over the fact thats theres no gravity . . how does the heaviness help him . .

216 J it keeps him on the ground

217 I uhum okay

218 J uhum

219 I and what happens so . . here if he wa:s particularly heavy then tripping over is not going to matter at all

220 J oh I dont know . he could fall down then couldnt he points into crater

In this paper I have attempted to describe a method of exploring school children's understanding of science. I have argued that it is only by being aware of their perceptions of events, and meanings of words, can physics teachers challenge their viewpoints. To teach physics is to modify and enhance pupils' concepts, skills and attitudes concerning the subject. The interview is a powerful and flexible method of exploring a youngster's conceptual framework. I have given some examples of the children's insight into the concepts of 'force' and 'energy', both separately, and as related concepts.

In physics, our concept of energy is closely tied to our concept of force; they are both abstract and difficult concepts to grasp. To teach them effectively we must build on the pre-determined knowledge of the learner and so avoid them becoming like the elusive grin on the Cheshire Cat.

Mike Watts, 1980

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